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Observations on heat generated in single point incremental forming

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Abstract

The forming tool in single point incremental forming (SPIF) follows a path prescribed by CAM software. As the tool follows this path, thereby deforming the sheet, both friction and deformation occur generating heat. The effect of increasing feed rates and tool rotation speed on resulting temperatures has been studied for AA 5754-H32. A flat tool was used to form a variable wall angle geometry and the temperatures were recorded using an infrared camera. The infrared camera was able to give a temperature gradient at the tool-sheet interface. It was found that along with geometry, lubricant and rig design also have an impact on the net heat within the system. In addition, beyond a certain limit, the high relative velocity can cause wear at the tool-sheet metal interface. The observations on temperature distribution are new and novel.

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Keywords: Single point incremental forming (SPIF), frictional heating, thermal imaging, tool rotation, feed rate

1. Introduction

Small scale production and prototyping requires a flexible and cost effective sheet manufacturing techniques with simple tooling. Single point incremental sheet forming (SPIF) is one such promising sheet metal forming technique that has become a prolific field of research, especially since the CIRP keynote publication [1]. Aluminum alloys such as 5XXX series are an important material in the automotive industry, due to their excellent corrosion resistance and high strength to weight ratio without compromising the vehicle quality [2]. However, lower formability of aluminum-magnesium alloys at room temperature remains a problem. Studies have suggested the forming of 5XXX aluminum alloy series at elevated temperatures and low strain rates improves formability significantly [3].

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This work aims to study the effect of single point incremental forming on AA 5754-H32 with a flat tool, forming a truncated lobe conical shape with a ridge in wall angles. Experiments reported here were conducted at different rotation speeds with a constant step down at different feed rates.

A preliminary observation is that at the speeds studied, the process for particular combinations is very similar to friction stir welding. This will be explored further elsewhere. The observations on temperature distribution are new and novel.

2. Theory

Frictional heating occurs in sliding and rolling contact where there is relative motion, as in single point incremental forming. Hence, heating is concentrated only over the area where tool makes contact dynamically with the sheet being formed. Frictional heating can be significantly high and may dynamic crystallization as demonstrated by some studies [4,5]. These temperatures can also be high enough to cause unwanted phenomenon such as oxidization or wear. The relation between sliding velocities and heat generated per unit area of contact at the surface interface is estimated by:

$$Q = F \times V \times t \quad (1)$$

Where, F is the frictional force, V is the relative sliding velocity and t is the time. Time during which tool makes contact with a point on the sheet is dependent on the selected feed rate.

In the case of single point incremental sheet forming, relative sliding velocity can be written as:

$$V = 2\pi r\omega \pm f \quad (2)$$

Where, r is the tool radius, ω is the tool rotation rate and f is the feed rate dependent upon the tool direction.

3. Experimental Details

3.1. Material

2.03 mm thick AA5754-H32 sheet was used to conduct the experiments. Material characterization was conducted at room temperature in accordance with ASTM E8/E8M-09. The strain hardening relationship is

$$\sigma = 393\varepsilon^{0.095}\ MPa \quad (3)$$

3.2. Forming Geometry

The geometry shown in Fig.1, and used for the experiments, is a truncated lobe conical shape with a ridge at half its depth [6]. It was selected to generate stress concentrations at the end of the ridge and observe the formability for the next part of the geometry. The main aim of the selected geometry was to create localized stresses by creating an additional step [7]. The “friction stir heating” in the forming zone can reduce the required flow stresses whereas, the surrounding unaffected regions can provide the necessary support for successful sheet forming. Variable wall angle